Soft Robotics Programmed with Double Crosslinking DNA Hydrogels

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Stimuli responsive materials have important significances in drug delivery, diagnostics, catalytic reactions, actuators, sensors, etc. One of the most well-known and attractive smart materials is stimuli-responsive hydrogel,[1] which is able to change their volumes significantly in response to alterations of certain environmental parameters. However, most currently available hydrogel materials respond to only a limited number of non-specific triggers, such as pH, temperature and light illumination,[2] which makes it very challenging to achieve highly accurate, programmable control of dynamic materials. As a result, novel systems that are able to yield addressable controls onto specific domains is highly desirable in metamorphic materials and soft robots.

DNA nanotechnology has been extensively studied to construct dynamic responsive systems.[3] Nevertheless, it is rare to see successful applications of DNAs in the macroscopic regime of material sciences. Here we demonstrated a novel strategy to magnify the nanometer scale DNA self-assembly into a macroscopic mechanical responsiveness (Figure 1). By incorporating molecularly engineered DNA sequences into a polymeric network, we were able to create a new type of responsive hydrogel (D-gel), whose overall morphology was dynamically controlled by DNA hybridization induced double crosslinking (Figure 2). As a step towards manufacturing, projection lithography was employed to rapidly create modular macroscopic structures out of the D-gel that featured programmable reconfiguration and directional movement, which could even mimic the complex gestures of human hands (Figure 3). Mechanical operations such as catch and release have been demonstrated by a proof-of-concept hydrogel palm, which possessed great promise for future engineering applications. Compared with previously developed DNA hydrogels, the D-gel featured an ease of synthesis, faster response, and a high degree of programmable control. Moreover, it is possible to scale up the production of D-gel containing responsive devices through direct 3D printing.

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[2] Z. Zhao, N. Hamdan, L. Shen, H. Nan, A. Almajed, E. Kavazanjian, X. He, Environmental science & technology **50**, 12401 (2016).
[3] A. V. Pinheiro, D. Han, W. M. Shih, H. Yan, Nature nanotechnology **6**, 763 (2011).

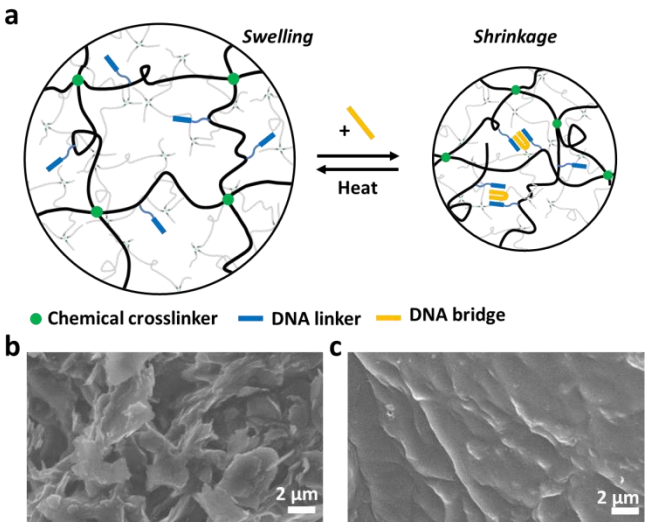

Figure 1: Responsive mechanism of the D-gel. (a) Scheme of working mechanism. (b) SEM image of a D gel before adding DNA bridge. (c) SEM image of a D gel after adding DNA bridge.

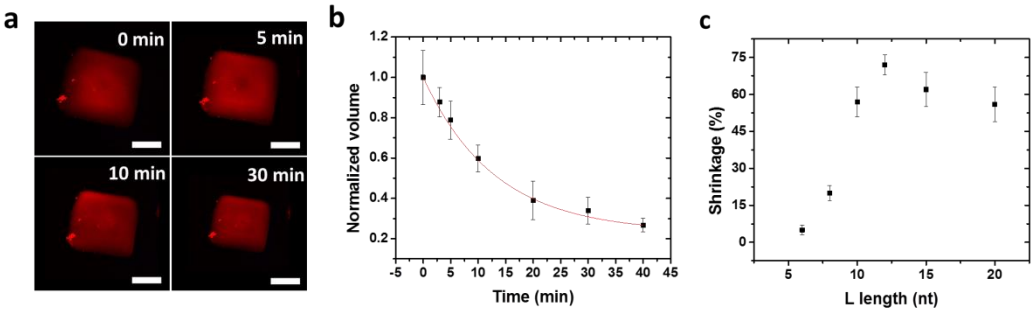

Figure 2: Study on the responsiveness of D-gel. (a) Time lapse images of a D-gel square after adding DNA bridge. (b) Normalized volume change of D-gel squares as a function of time after introducing DNA bridge. (c) Shrinkage of D-gel squares as a function of the length of DNA linker.

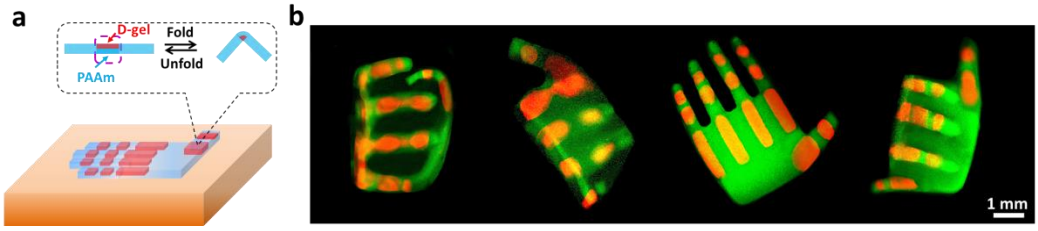

Figure 3: Control the movement of hydrogel palms with DNA triggers. (a) Scheme of the fabrication strategy. (b) Representative fluorescent image of a hydrogel palm that can make various gestures.